Cold Dust in the Eagle Nebula. Photo Credit: ESA, ISO, ISOGAL Team

Astrophysics Branch (SSA) Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. SSA researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations of the universe and new instrumentation developed to make these observations.

Jesse Bregman

Deputy Chief, Astrophysics Branch (SSA)

IDENTIFYING POLYCYCLIC AROMATIC HYDROCARBONS IN SPACE

Jesse Bregman and Pasquale Temi

Polycyclic aromatic hydrocarbon (PAH) molecules are the most abundant family of molecules in the interstellar medium after molecular hydrogen and carbon monoxide, and contain about 10% of all the interstellar carbon. They are extremely tough molecules, are a component of meteorites, and thus were likely delivered to the early earth where they may have played an important role in the formation of life. Until recently, the only way to study PAHs in the interstellar medium by examining their emission spectrum. PAHs fluoresce when present near sources of bright ultraviolet radiation such as exits in planetary nebulae and HII (ionized hydrogen) regions. PAH absorption spectra have been measured in laboratory studies, but these spectra cannot be directly used to determine the mix of PAHs that occur in the interstellar medium without using complex models. There are enough unknowns in the models that definitive statements about the exact nature of the interstellar PAHs has so far been impossible.

Recently, a spectral database has become available from the Infrared Space Observatory that contains objects in which we have found the C-H PAH stretch feature (near 3.26 µm) in absorption. Using the database of isolated neutral PAHs generated by the Ames Astrochemistry Laboratory, we can match the interstellar feature fairly well with a mixture of PAH molecules. However, the mixture is not unique and does not tell us which particular PAHs are present in space. This is demonstrated in Figure 2 which shows two fits to the absorption observed towards the protostellar source S140. The laboratory database contains only a few PAHs as large as those expected to survive the rigors of the interstellar medium, so it is perhaps not surprising that a precise match is still not possible. Techniques for obtaining lab spectra of larger PAHs exist, but making large PAHs for lab studies is very difficult. Once such lab data exist, being able to directly compare lab and interstellar spectra without using uncertain models could provide the first identification of individual PAHs in space. ❑

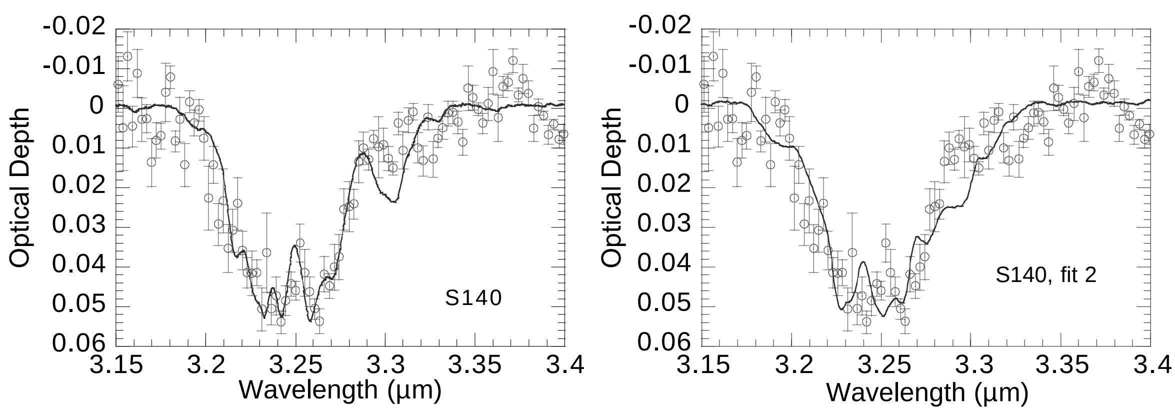

Figure 2: The spectrum of S140 has been divided by an estimate of the continuum to allow direct comparison with laboratory data of PAHs. The two panels show different mixtures of laboratory PAHs (solid lines) plotted on top of the S140 data points.

THE AIRES FAR INFRARED DETECTOR ARRAY

Edwin Erickson, Jessie Dotson, Jam Farhoomand, Christopher Mason

A unique, state-of-the-art array of detectors is being developed as part of AIRES, the Airborne Infrared Echelle Spectrometer for SOFIA (the Stratospheric Observatory for Infrared Astronomy). SOFIA is a Boeing 747 which will carry a 2.7-meter telescope to operating altitudes up to 45,000 feet. It is under development by NASA and the DLR (German aerospace center). SOFIA is scheduled to begin operations at Ames in late 2004. AIRES — which is being built at Ames — is the facility spectrometer for SOFIA. AIRES will measure atomic and molecular spectral lines at far-infrared wavelengths, roughly 30 to 400 times the wavelengths of visible light, to probe physical characteristics of astronomical sources such as star forming regions and our Galactic center.

Here we describe highlights of the AIRES detector development. Infrared light collected by the SOFIA telescope will be distributed by the optical system of AIRES to its semiconductor detectors so as to permit simultaneous separation of different wavelengths in each of 24 imaging picture elements (pixels) viewing the sky. The detectors will be arranged in a 16x24 rectangular grid with pixels spaced 8 hundredths of an inch apart. Each detector is a chip of antimony-doped germanium mounted in an integrating cavity and fed with light from the spectrometer by a conical light collector, shown in Figure 3.

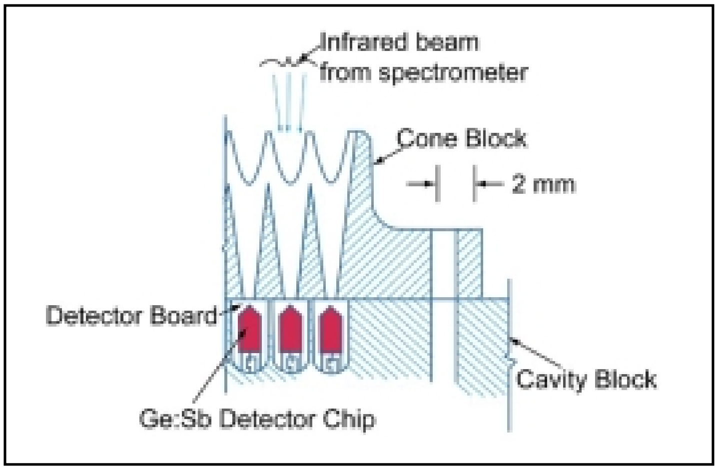

Figure 3: Detail of the AIRES far infrared detector geometry.

The AIRES optical system and detector assembly will be cooled in a cryostat to a few degrees Kelvin, as required to achieve the highest possible sensitivity to the infrared radiation collected by the SOFIA telescope. The detectors convert the light from the spectrometer into electrical signals. These are amplified and multiplexed by adjacent integrated circuits that route the signals to the data system outside the cryostat.

These unique multiplexing amplifiers were designed specifically for AIRES by industrial specialists collaborating with AIRES team members. The device technology was originally developed for SIRTF

(Space Infrared Telescope Facility), but the new circuits are tailored for the wider range of infrared backgrounds expected on SOFIA. They feature externally programmable gains to accommodate different observing conditions, and so will be suitable for a variety of SOFIA instruments as well as some spaceborne instruments. The AIRES team pioneered this development, and has tested several devices, confirming that their cryogenic noise and gain performance meets AIRES needs.

The entire detector package — detectors, amplifiers, and array assembly — is custom designed and built, with much of the work done at Ames by the AIRES team. In previous tests the detector configuration sketched in Figure 3 was shown to work well. During fiscal year 2000, testing of the amplifiers and design and fabrication of a 2x24 protoflight detector module have made great progress. This unique detector system, essential for AIRES' success, is well on its way to achieving its design performance. ❑

THE WORLD'S LARGEST GRATING

Michael R. Haas, James A. Baltz, Edwin F. Erickson, Emmett I. Quigley, and David C. Scimeca

The Airborne Infra-Red Echelle Spectrometer (AIRES) is a high-resolution grating spectrometer under development as a facility science instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA). An echelle is a grating used at a steep angle of incidence relative to the incoming light beam. The spectral resolution of a grating spectrometer is directly proportional to the projected length of its grating along this beam and inversely proportional to the wavelength of light being analyzed. AIRES is designed to measure far-infrared (long-wavelength) spectral lines of molecules and atoms originating in the interstellar medium. Therefore, AIRES requires a grating significantly longer than any previously made. In fact, the wavelength range and resolution planned for AIRES demands the World's largest grating!

Further, the entire AIRES optical system must be operated at a few degrees Kelvin (near absolute zero). To minimize problems associated with thermal contraction in this cryogenic environment, to facilitate diamond machining, and to ensure long-term stability, a monolithic aluminum blank was chosen. This blank was manufactured from 152-mm thick, aluminum alloy 6061-T651, Type 200 tooling plate. The final blank is 102 mm thick, 267 mm wide, and 1067 mm long with the corners removed to provide a near-elliptical planform. The blank was light-weighted by cutting triangular-shaped slots with a wire-electric-discharge machine, which builds less stress into the blank than conventional milling and has the ability to cut deep slots with small corner radii. The resulting truss-like structure is symmetric, provides good specific stiffness, and is 70% light weighted. Before final machining, the blank was heat-treated at 375∞C for two hours and then thermally cycled 7 times between -200∞C and 100∞C to obtain the required stability.

A groove spacing of 980 microns, an apex angle of 90 degrees, and a blaze angle of 76 degrees were selected to optimize the packaging and optical performance of the grating at the wavelengths of interest. This combination of parameters maximizes the spectral resolution for the 63- and 145-micron neutral oxygen, 157-micron singly ionized carbon, and 205-micron singly ionized nitrogen transitions arising from the interstellar medium, without adversely effecting performance for other high-priority transitions.

The grating was ruled under contract with Hyperfine, Incorporated of Boulder, CO, with a fly cutter using single-point diamond turning on a custom ruling engine. The completed grating is shown in Figure 4. The light-weighting truss structure is evident along its front edge. Two reflections of the technician are visible; the front reflection originates on the long, 14-degree groove facets and the rear reflection originates on the steep, 76-degree groove facets.

To achieve the desired optical performance, the AIRES optical system must have a total root-mean-square (RMS) wave-front error (WFE) less than 1.5 microns. A detailed error analysis apportioned 0.8 microns RMS WFE to the echelle grating. This WFE includes contributions from both absolute and periodic errors in groove position, shape, straightness, and fanning, as well as gross deflections of the blank due to self-weight, tool forces, and variations in thermal contraction. Interferometric tests of the completed grating measure a WFE of 0.3 microns RMS – much better than required. This implies that the surface is flat to about one part in 7 million. Other optical tests confirm that the efficiency and scattered light properties of this grating are acceptable for use in AIRES. The World's largest echelle grating has been successfully ruled and tested; the associated opto-mechanics, cryostat, detectors, and software for AIRES remain under development. ❑

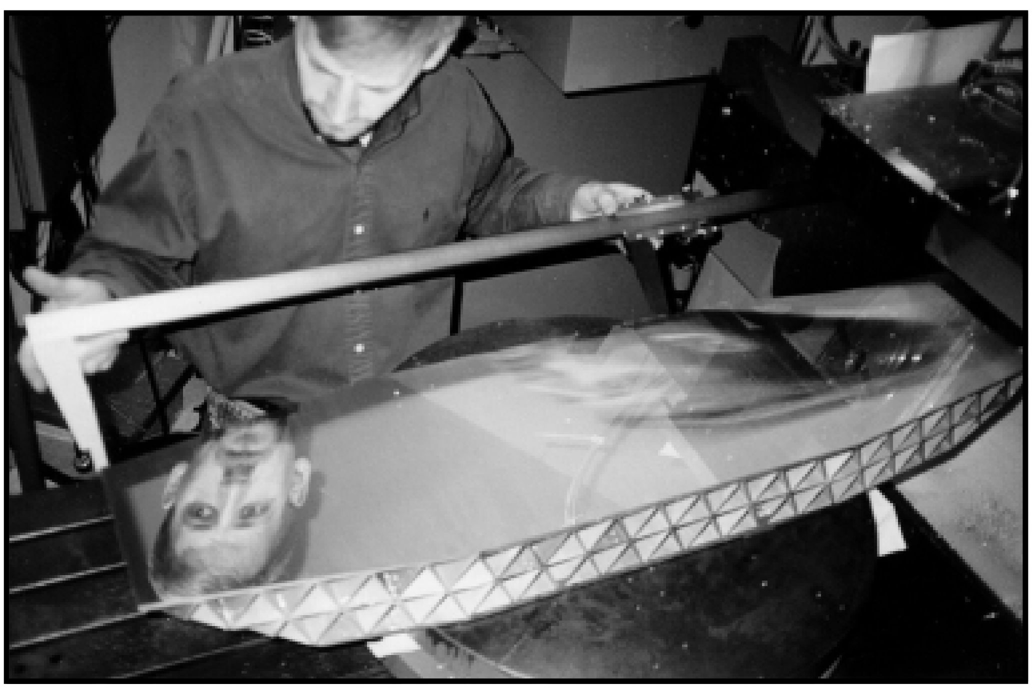

Figure 4: The AIRES echelle is the largest monolithic, fully-phased grating in the World.

THE SOFIA WATER VAPOR MONITOR

Thomas L. Roellig, Robert Cooper, Brian Shiroyama, Regina Flores,
Lunming Yue, and Allan Meyer

The Stratospheric Observatory for Infrared Astronomy (SOFIA), a 3-meter class telescope mounted in a Boeing 747 aircraft, is being developed for NASA by a consortium consisting of the University Space Research Association, Raytheon E-Systems, and United Airlines. This new facility will be a replacement for the retired Kuiper Airborne Observatory that used to fly out of Moffett Field. As part of this development, NASA Ames Research Center is providing an instrument that will measure the integrated amount of water vapor seen along the telescope line-of-sight. Since the presence of water vapor strongly affects the astronomical infrared signals detected, such a water vapor monitor (WVM) is critical for proper calibration of the observed emission. The design and engineering model development of the water vapor monitor is now complete and the hardware to be used in the flight unit is being fabricated and tested.

The SOFIA water vapor monitor measures the water vapor content of the atmosphere integrated along the line-of-sight at a 40° elevation angle by making radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. These measurements are then converted to the integrated water vapor along the telescope line-of-sight. The monitor hardware consists of three physically distinct sub-systems:

1) The Radiometer Head Assembly, which contains an antenna that views the sky, a calibrated reference target, a radio-frequency (RF) switch, a mixer, a local oscillator, and an intermediate-frequency (IF) amplifier. All of these components are mounted together and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a microwave-transparent window. The radiometer and antenna were ordered from a commercial vendor and have been modified at Ames to include an internal reference calibrator. Laboratory tests of this sub-assembly have indicated a signal-to-noise performance over a factor of two better than required.

2) The IF Converter Box Assembly, which consist of IF filters, IF power splitters, RF amplifiers, RF power meters, analog amplifiers, A / D converters, and an RS-232 serial interface driver. These electronics are mounted in a cabinet just under the radiometer head and are connected to both the radiometer head and a dedicated WVM computer (CPU). All of the flight electronics boards have been fabricated and have been shown through testing to meet their requirements. A small microprocessor that handles the lowest level data collection and timing has been programmed in assembly language to collect and co-add the radiometer data and communicate with the software residing in the WVM CPU.

3) A dedicated WVM CPU that converts the radiometer measurements to measured microns of precipitable water and communicates with the rest of the SOFIA Mission and Communications Control System (MCCS). A non-flight version of this computer hardware has been procured for laboratory testing and the flight software is under development, with approximately 60% of the software coded and unit-tested. Proper command and data communications between the Water Vapor Monitor and the SOFIA MCCS have been demonstrated using an MCCS simulator located on-site at Ames that has been developed by the SOFIA Project. ❑

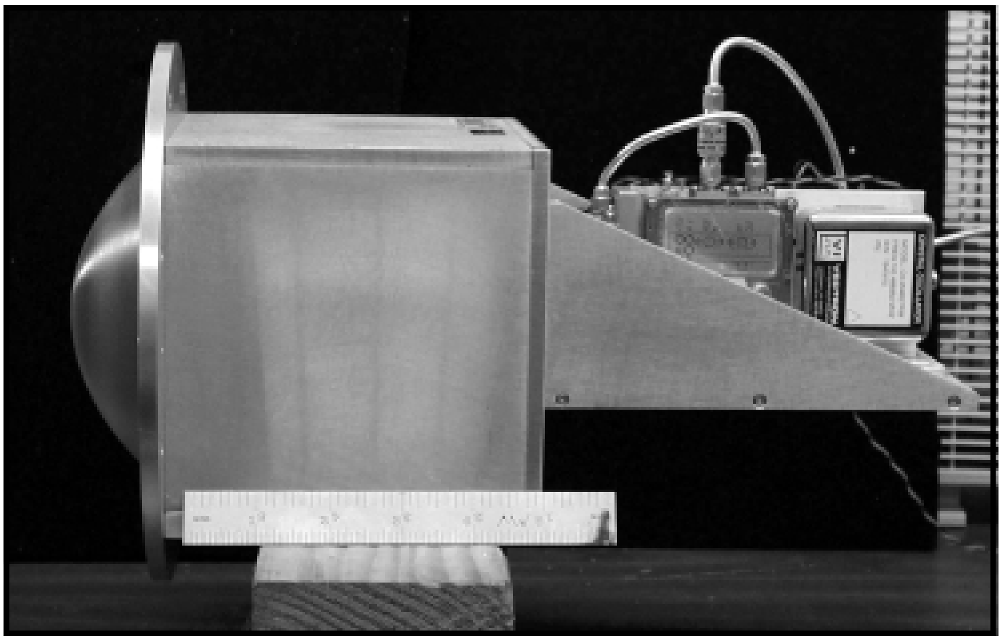

Figure 5: The SOFIA Water Vapor Monitor 183 GHz Radiometer Assembly

AMES NEW INTERSTELLAR SIMULATION CHAMBER. CAVITY RING DOWN SPECTROSCOPY OF INTERSTELLAR ORGANIC MATERIALS

Farid Salama, Ludovic Biennier, Robert Walker, Lou Allamandola, Jim Scherer, and Anthony O'Keefe

A major milestone has just been achieved at Ames. A new facility has been developed to directly simulate gaseous molecules and ions at the low temperature and pressure conditions of interstellar space. This laboratory facility -that is unique within NASA- combines the techniques of Supersonic Free-Jet Expansion Spectroscopy (JES) with the techniques of Cavity Ring Down Absorption Spectroscopy (CRDS). The principle objective is to determine the spectroscopic properties of large interstellar aromatic molecules and ions under conditions that precisely mimic interstellar conditions. The aim of this research is to provide quantitative information to analyze astronomical spectra in support of NASA's Space Science and Astrobiology missions, including data taken with the Hubble Space Telescope.

Understanding the origin, physical properties, and distribution of the most complex organic compounds in the universe is a central goal of Astrophysics and Astrobiology. To achieve this requires generating and maintaining large carbon-containing molecules and ions under interstellar-like conditions while simultaneously measuring their spectra under these conditions (i.e., in the gas phase at very low densities and at very low temperature). As an aside, these organic structures are those that constitute the building blocks of carbon nanotubes. This has been accomplished by combining three advanced techniques: free supersonic jet expansion, low-temperature plasma formation and the ultrasensitive technique of cavity ring down spectroscopy. The new facility comprises thus a pulsed-discharge, supersonic slit jet source mounted in a high-flow vacuum chamber and coupled to a cavity ring down spectrometer. Under these experimental conditions, a beam of argon or helium gas seeded with polycyclic aromatic hydrocarbon molecules (PAHs) is expended in the gas phase into the cavity ring down chamber. When the expanding beam is exposed to a high-voltage ionizing electronic discharge, positively charged ions are formed that are characterized by very low, interstellar-like, rotational and vibrational temperatures (temperatures of the order of 10 and 100 K respectively are achieved this way as shown in Figure 6). Recording the cavity ring down signal is a direct measurement of the absolute absorption by the seeding molecules and ions. This is illustrated in Figure 7 that shows the spectrum of the PAH naphthalene ion ($C_{10}H_8^+$). This unique experimental facility has been developed in collaboration with Los Gatos Research through a Small Business Innovative Research (SBIR) contract.

The data shown in Figure 7 can now be used to analyze the astronomical spectra. For example, the absorption band of the PAH ion $C_{10}H_8^+$ shown in Figure 7 can be directly compared to the absorption spectrum of the diffuse interstellar bands (DIBs). These bands that contribute to the global interstellar extinction were discovered eighty years ago and remain an enigma to this day.

For the first time, the absorption spectrum of large organic molecules and ions can be measured under conditions that mimic entirely the interstellar conditions. ❑

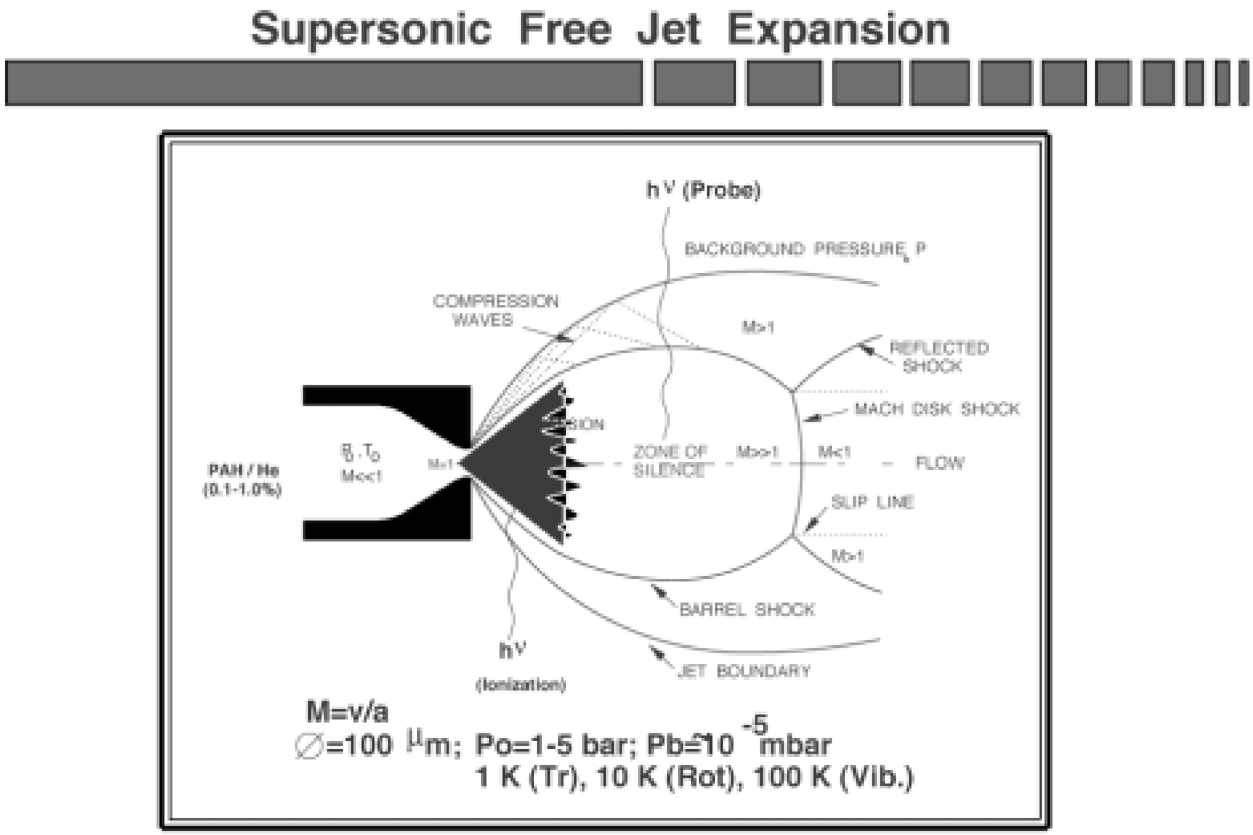

Figure 6: The figure shows the location of the "zone of silence" in a supersonic free jet expansion. The physical conditions within the boundaries of the "zone of silence" approach interstellar conditions.

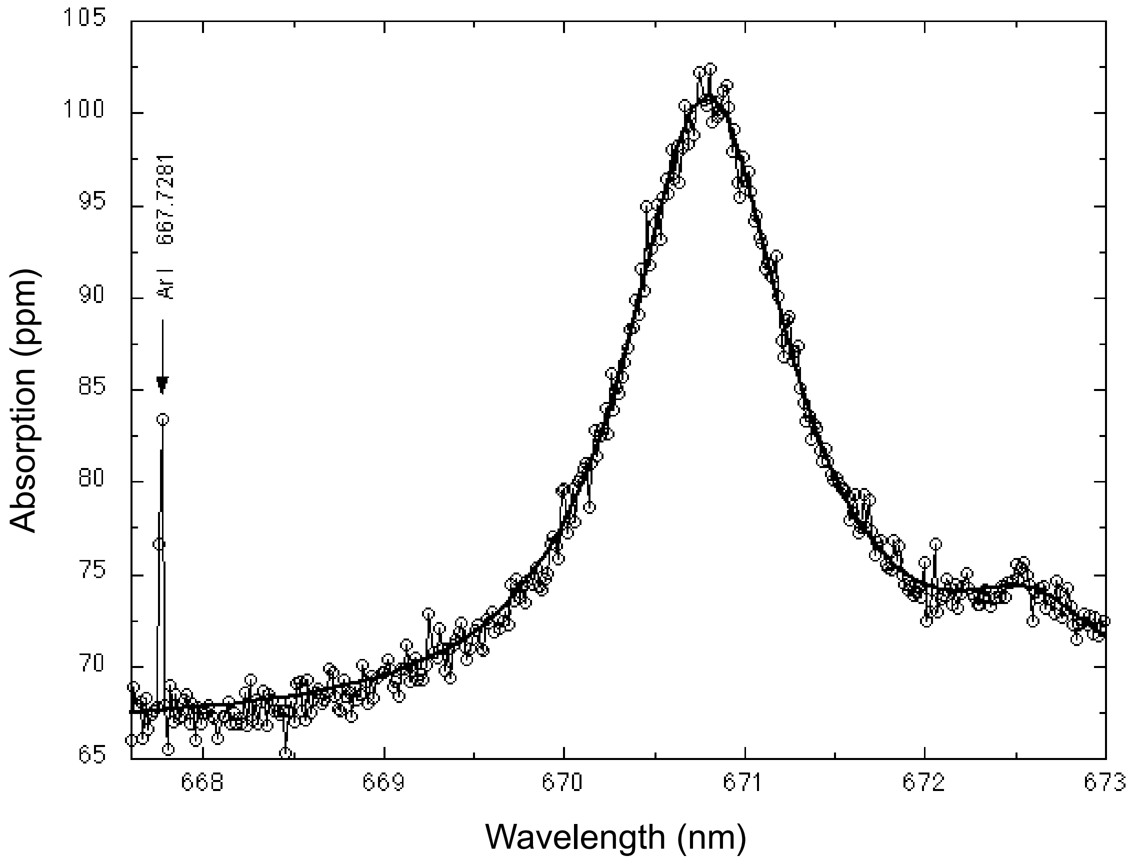

Figure 7: The CRDS absorption spectrum of the naphthalene cation ($C_{10}H_8^+$) under simulated interstellar space conditions. The spectrum is obtained when an argon free jet expansion seeded with naphthalene is exposed to a high-voltage discharge. Note the absorption line of metastable argon that is used for internal wavelength calibration.